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VERTICAL AIR MOTION IN SHOWERS AS REVEALED
BY DOPPLER RADAR

By J. R. PROBERT-JONES, B.A. and W. G. HARPER, M.Sc.

The Doppler principle has had many and varied applications in physics and in astronomy, but has only recently been applied to meteorology as a radar technique. The Meteorological Research Unit of the Meteorological Office at Malvern, with the active help of the Royal Radar Establishment, Ministry of Aviation has been applying it to a study of precipitation processes. A Doppler radar working at centimetric wavelengths, pointed vertically, will measure the fallspeeds of precipitation, and if it is also a pulsed radar it will measure these fallspeeds at any specified height. In warm-front rain, where the vertical air motion is small (a few centimetres per second) we can in effect measure the free air terminal fallspeeds of the raindrops, and, from the intensity of the echo received from each velocity interval, we can obtain information on the variation of drop distribution with height [1, 2].

Quite a different method of analysis is necessary in convective precipitation, where updraughts and downdraughts can be expected to have values measured in metres per second rather than centimetres per second, and where the velocities measured by the Doppler radar will be the free air fall velocities of the precipitation particles modified by these vertical air motions. Plate I(a) (facing p. 276) is a Doppler pattern from the active portion of a moderate summer shower with its top at about 5 km. This record was obtained on 8 June 1961 at Pershore, Worcestershire using the 3.2 cm 10 kw pulsed Doppler radar described by Boyenval[1]. The equipment was used pointing vertically. Height elements, each about 150 m (500 ft) in depth, are displayed along the vertical axis, and precipitation fall velocities along the horizontal axis, in channels 1 m/sec wide. The zero velocity channel is defined by the strong echo in the lowest height elements, which is caused by transmitter break-through and by sidelobe reflections from stationary ground targets. Since we are working at 3.2 cm wavelength and are using a comparatively low output power we can assume that we are not detecting cloud particles as such, but only the precipitation present.

Above the 0°C level at 1.5 km in Plate I(a) the pattern shows considerable

variability with height, with substantial excursions from the mean*, but the whole pattern can be seen to trend first one way and then the other with height. The radar beam is quite a narrow one (up to May 1960 it was 3° wide to half-power points, or 260 m at height 5 km, and less in proportion at lower heights; but in May 1960 a larger aerial was installed giving a beam 1.7° wide, or 150 m at height 5 km) and is unlikely to have enclosed both a region of upward and one of downward air motion at any one time and at any one level. We can therefore attribute the breadth of the velocity spectrum, which changes only gradually with height, primarily to the range of particle sizes present at each level, and the main zigzag effect to the spatial variability of the vertical air motion. At 3 km and at 4 km in Plate I(a) some precipitation is actually rising at 1 to 2 m/sec, and it is clear that at these levels upward air motion must be present.

By comparison with this variability the pattern found towards the rear of the same shower (Plate I(b)) is a very simple one. It has a strong resemblance to the patterns obtained in warm-frontal rain. The low velocities above the 0°C level, their narrow spectrum, and the rather small excursions from the mean suggest that this is a fallout zone with only snow and ice crystals present, and that there is little vertical air motion at these levels.

Below the 0°C level, however, at both times, in the first kilometre or so above the ground, the pattern changes very little with height. The simplest interpretation is that there is a stable spectrum of raindrop sizes, and a rather uniform vertical air motion at these levels. The spectrum extends to the 9 m/sec channel at 1250 GMT, but only to 6 m/sec at 1235 GMT. We shall show that this is partly an effect of vertical air motion, but mainly of maximum drop size. The rainfall at the ground was very light at 1235 GMT. This will be examined in more detail later. In both patterns the precipitation echo disappears completely below about 400 m. This is entirely an instrumental effect, caused by receiver paralysis in the first few microseconds after the emission of the radar pulse, and does not imply any weakening of the precipitation near the ground.

An interesting feature is that an acceleration zone has been present at the melting level in all the Doppler shower records so far examined. At first sight this seemed surprising, because it was known from experience that a bright band, which is the accepted indicator of melting effects on a conventional weather radar, though often seen in showers on a normal range–height radar, is certainly not always present. Browne[3], however, working at Cambridge, England with a vertically-pointing 3 cm radar, had reported that bright band effects were nearly always detectable in showers as well as in stratiform rain, and our Doppler records, though rather few in number, seem to support his claim. It may be that in shower conditions bright bands are seen less often on range–height radars than on vertically-pointing radars because with the range–height display we are usually working at much greater ranges where width of beam results in poorer discrimination. There would thus be a tendency to mask weak bright band effects. It is understandable that a pulsed Doppler radar, with its ability to sort the components of precipitation by virtue of their varying fallspeeds, might detect an acceleration effect at the melting level on occasions when spatial variability of the particle distribution tended to mask

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*Care must be taken when examining the patterns to exclude any effect due to the harmonic component which is seen in Plate I(a) as a weak mirror image of the main trace.

it on an ordinary display. Plate I(a) is probably an example of this. The rain-fall rate at the ground at this time was small, but there was almost certainly much heavier precipitation aloft which could have blotted out a small intensity maximum at the melting level on an RHI radar. Three-centimetre range–height records were in fact taken on this storm but a bright band was not seen.

Method of analysis.—The assumption which has been made in order to derive vertical air velocities in showers is based on this consistent detection of an acceleration zone at the melting level in the Doppler records. It is suggested that to explain it there must have been a component of the precipitation just above the 0°C level in these showers consisting of large ice crystals or snow-flakes, and that these collapsed on melting to form raindrops with much higher fall velocities than the snow. There may in addition have been super-cooled waterdrops or other forms of precipitation such as graupel or hail present, but our Doppler technique would record them in greater downward velocity channels than the snow, and they would not mask the acceleration effect at the right-hand edge of the recorded pattern. The snowflakes and ice crystals which we infer were melting in the acceleration zone must have grown at a substantially higher level, and it is assumed as the basis for the analysis that they are present at all higher levels in the precipitation. Only small concentrations would be needed for detection since with the vertically-pointed aerial the ranges of detection are short. Measurements made by Langleben[4] show that snowflakes and ice crystals have a free fall velocity of about 1 m/sec ($\pm \frac{1}{2}$ m/sec). Our method therefore is to define the right-hand edge of the pattern to the nearest metre per second at each level, correct it by 1 m/sec, and so obtain a value of vertical air motion for each height element.

Before considering the implications of this method the recording technique must be described in more detail. An effectively continuous record of the Doppler display is obtained by using special Vinten cameras, in which the shutter is open continuously apart from the short interval, a small fraction of a second, when the film is being moved on. An exposure is taken every five seconds and each is therefore a five-second integration of the pattern. This has seemed acceptable because we do not see obvious changes or rapid oscillations in velocity within a five-second period; in fact the time variation in the velocity pattern has been sufficiently slow that only each second or third frame in the analysis has been used. In a shower extending to 6 km and taking 20 minutes to pass over the radar this gives us over 4000 measurements. They are plotted on an open scale of height against time, and isopleths are drawn at intervals of 1 m/sec. Very little smoothing has been necessary, but individual measure-ments differing by 1 m/sec from the surrounding values have been ignored. The smallest features drawn in the patterns are from two or three contiguous values. Finally, a horizontal scale in kilometres is added, based on the assump-tion that the shower is moving with the speed of the wind at 3 km, and the pattern is then redrawn to a uniform scale in the vertical and horizontal, and is reduced to a convenient size.

To extend the analysis below the melting level a different assumption is necessary. From an assumed continuity of vertical air motion at the melting level the terminal velocity of the drops present immediately below this level can be inferred, and from the further assumption that there will be little change in the terminal velocity of the largest drops in their fall to the ground (the largest drops are least modified in size by evaporation during fall) we can

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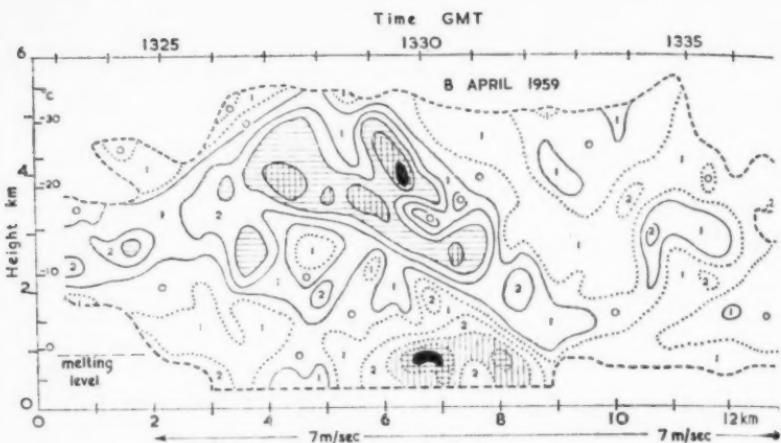
FIGURE 1—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
8 APRIL 1959 (*continued opposite*)

The left-hand side being earliest in time is the leading edge of the shower. Wind speeds are given in knots (1 m/sec=2 kt).

interpret the left-hand edge of the pattern below this in terms of vertical air motion. The method does not take into account any change of drop distribution due to shear across the beam.

It must be borne in mind when studying the patterns that each is a single cut through the shower. Further, since the horizontal velocities of the showers were substantially greater than the vertical velocities which were measured, the patterns will be more closely akin to instantaneous range–height patterns than to the patterns that would be recorded if one could move one's axis of measurement with the storm. In all cases (e.g. Figure 1) the left-hand side being the earliest in time is the leading edge of the shower. The isopleths have values $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$ . . . m/sec. For simplicity the zones between them have been labelled 0, 1, 2 . . . m/sec, upward motion being enclosed by full lines and downward motion by dotted lines. We present here the patterns obtained in three moderate showers.

Shower of 8 April 1959.—On both 8 and 9 April 1959 moderate showers were widespread over England and Wales in moist unstable westerlies of maritime polar origin, but amounts of rain were small. 1.5 mm of rain were measured in the shower which gave echo in the vertically-pointing beam of the radar from 1323 to 1349 GMT on 8 April. Cloud at the time was reported as Cu and Cb with base at 450 m.

The first minute or so of echo overhead was missed, and the start of record shows echo only between 1.5 and 3.5 km, entirely above the melting level which was at 1.0 km (Figure 1). Three minutes later echo extends to the ground, and the echo top in the beam is at 5 km, where the temperature is −30°C. The pattern falls into three main sections. The first from 1323 to 1333 GMT is clearly the most active part of the shower. It contains the strongest upward and downward air motions. The great majority of upward air motion occurs above 2 km, with downward motion largely below this level. The

a Active section at 1235 GMT

*b* Decaying section at 1250 GMT
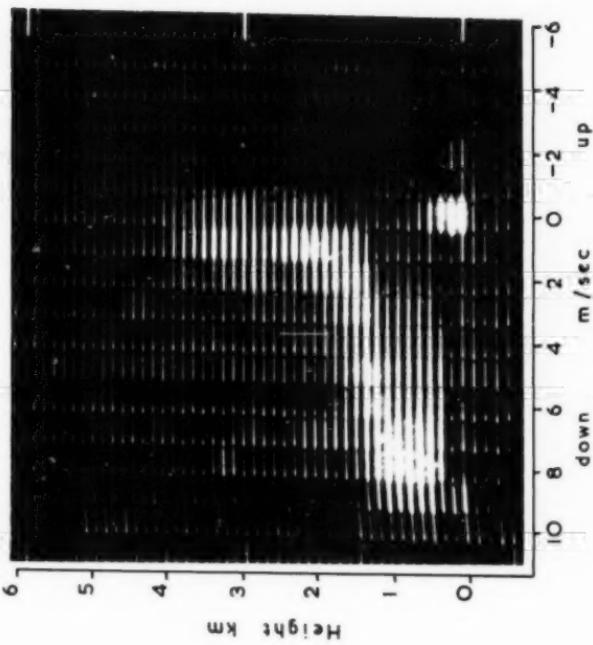
PLATE 1—PULSED DOPPLER RADAR RECORDS FROM A SHOWER ON 8 JUNE 1961 AS IT MOVED OVER THE RADAR
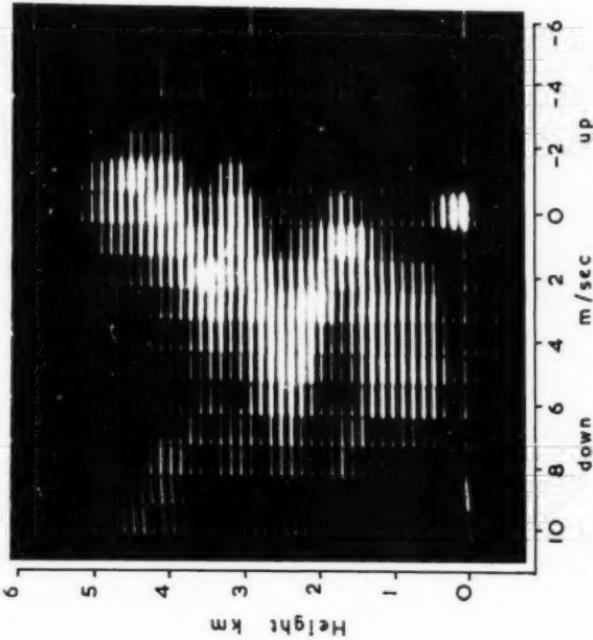
PLATE II—MACHINE OPERATORS AT WORK IN THE PUNCHED-CARD INSTALLATION
IN THE METEOROLOGICAL OFFICE, BRACKNELL
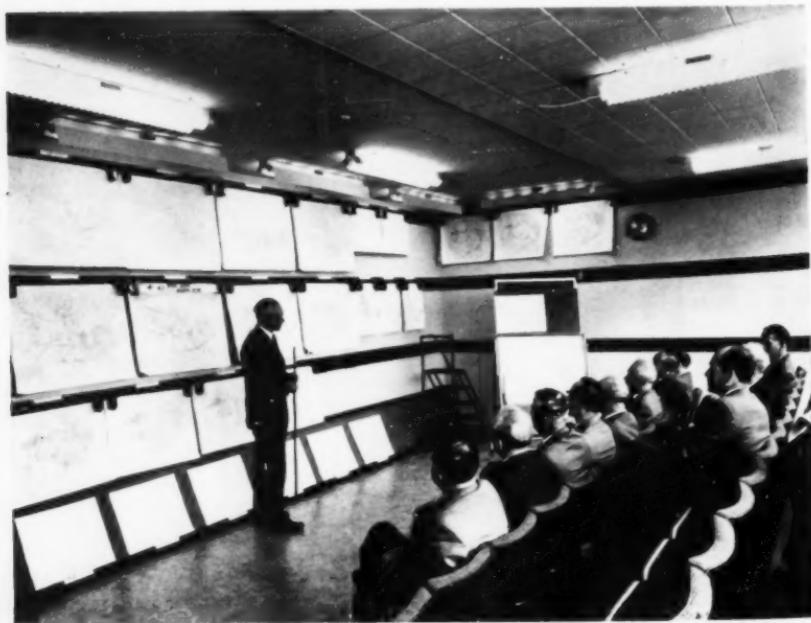
PLATE III—DAILY FORECAST CONFERENCE AT THE METEOROLOGICAL OFFICE,
BRACKNELL
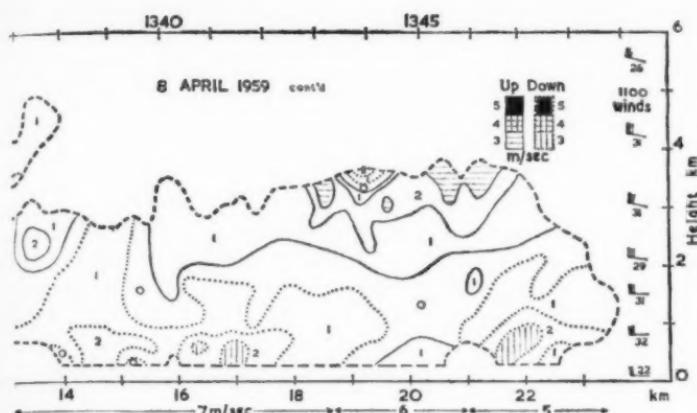
FIGURE 1—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
8 APRIL 1959—*continued*

upward motion is present initially in cells of 2 to 3 m/sec, but the maximum
values of 4 to 5 m/sec are found at the 4 km level, and seem to occur beneath
the highest tops. A surprising feature is the tilted zone of upward motion.
It does not seem possible to explain it as an effect of wind shear. The winds
given in the diagrams were measured at Aughton, 75 miles north of the radar
site, but it seems from the uniform pressure pattern prevailing at the time,
that the local winds at Pershore are not likely to have been very different.
The strongest downward air motions, also 4 to 5 m/sec, are found at low levels,
just before precipitation ceased at the ground at 1332 GMT.

In the second section from 1333 to about 1339 GMT the vertical air motions
are small and apparently disorganized, small downward motion predominating.
It is clearly a region of decay. The third section from 1339 to 1349 GMT may
in effect be a separate shower. It is again more organized, with upward motion
above 2 km and downward motion below. The upward motion of 3 m/sec
occurring in the highest echo top in this section possibly represents an actively
developing cell. The inferred terminal velocities of the largest drops, entered
below the horizontal scale of kilometres in the diagram, are 7 m/sec for most
of the shower, falling to 5 m/sec at its end. The values correspond to drop
diameters of 2.5 mm decreasing to about 1.5 mm. A tailing off of this kind
accords with experience, and is of course the effect of differential fall velocities
in wind shear. The raingauge also showed a maximum rainfall rate in the
early part of the shower.

An analysis was also made of the breadth of the spectrum of velocities
throughout the shower. It is not shown here, but its main features are described.
Below the melting level the breadth was 8 m/sec in the early part of the shower,
and a fairly steady 7 m/sec in the final section, but in section two its maximum
was only 4 m/sec and its average only 2 m/sec. Above the melting level it was
as high as 7 to 8 m/sec in the cells of maximum updraught, suggesting that the
maximum growth was associated with them. In the almost detached precipita-
tion recorded at 1337 GMT at around 4 km the echo was restricted to one and
occasionally two channels, strongly suggesting that this was a decaying tower

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falling away as snow. The comparatively slow changes found with height and time suggest that small-scale turbulence is contributing rather little to the breadth of the spectrum.

Very roughly we can see in Figure 1 a spacing of cells and regions of upward and downward air motion of about 1 to 2 km, both in the horizontal and the vertical. This is substantially greater than the resolving power of the systems either in the vertical or the horizontal, and one can be confident that it is not a scale imposed by the equipment.

Shower of 9 April 1959.—On the next day showers were again widespread, and some stations not more than 100 miles from the observing site reported hail, probably graupel. The cloud at Pershore was reported as Cu and Cb with base 600 m. Winds were lighter, and as a result the time scale of the shower
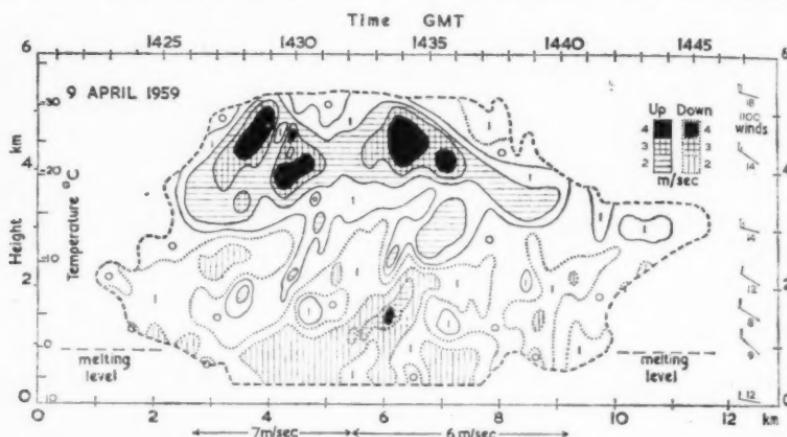

FIGURE 2—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
9 APRIL 1959

The left-hand side is the leading edge of the shower. Wind speeds are given in knots.

recorded on the Doppler radar (Figure 2) appears more compressed. The rain-gauge record shows that the rainfall rate was a maximum, 8 mm/hr, at the beginning of the shower. The gauge recorded 0.7 mm of rain, a modest shower. The terminal velocities deduced for the largest drops, 7 m/sec falling to 6 m/sec, fit reasonably with this. They imply a maximum drop diameter of 2.5 mm falling to 2.0 mm.

The pattern shows some obvious similarities to the shower of 8 April, but it should be noted that in Figure 2 the full black zones are 4 m/sec whereas in Figure 1 they were 5 m/sec. The upward air motion is concentrated in the top forward half of the shower, while the downward motion is largely below. The strongest upward motion of 4 m/sec is close to the top of the echo. The downward motion is shown as mainly 2 m/sec, but there is one cell of 3 to 4 m/sec in the middle of the shower just above the melting level, which was again close to 1 km.

There are other similarities between the two patterns. The first echo appeared well above the 0°C level, between 2 and 2½ km, and it was five minutes before

the shower reached the ground at the radar site, about the same time lag as on the 8th. At this time the echo top had almost reached its maximum of 5.3 km (temperature $-31°C$). The shower at the ground seems to have lasted for ten minutes, from 1427 to 1437 GMT, and then the echo base lifts and the echo top descends, the tail of precipitation being seen at 3 km at 1445 GMT. The Doppler pattern in the tail of this shower had all the characteristics of the decay stage (e.g. Plate I(b)), with echo above the melting level almost entirely restricted to the downward velocity channels of 1 and 2 m/sec. We can assume with confidence that this was the slow fall-out of snow, the remnants of earlier activity. The spacing of cells of air motion is again roughly 1 to 2 km. These patterns will be discussed further in a later paragraph.

Shower of 8 June 1961.—We have a complete Doppler record of this shower, and in addition range–height radar records from a 3-cm AN/TPS-10. An extract from these range–height records is given in Figure 3 covering the shower's history and movement for rather more than an hour before it reached the station, and for almost an hour after it had passed. We had not been equipped to obtain range–height records in 1959. The range–height patterns are not uniform in scale in the horizontal and vertical as are the vertical air motion patterns, but are much compressed in range as compared with height. It will be seen that the echo top rose from 5.0 to 6.5 km between 1118 and 1134 GMT, it was 5.5 km at both 1254 and 1303 GMT, but was 6.0 km again at 1324 GMT. At 1233 GMT 6.1 km was recorded by the Doppler radar. Throughout the whole period from 1134 to 1324 GMT the shower seems to have retained the same general form, with active towers at the front of the shower and decaying echo towards its rear. New growth seems to have been taking place almost underneath the overhang at the leading edge. The cores of strong echo shown
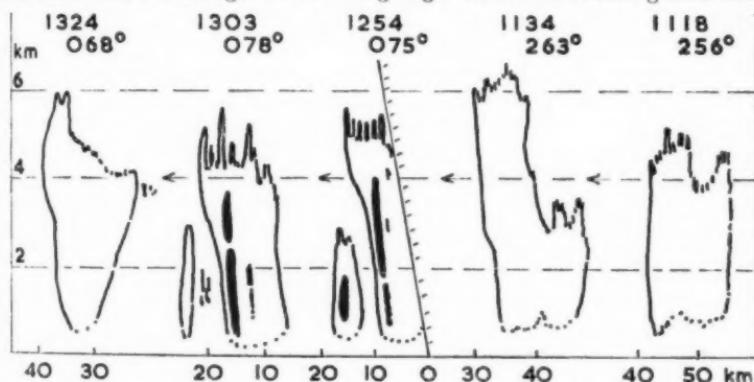
FIGURE 3—RANGE–HEIGHT CROSS-SECTIONS OF THE SHOWER OF 8 JUNE 1961 AT FIVE DIFFERENT TIMES SPREAD OVER A TWO-HOUR PERIOD FOR COMPARISON WITH THE DOPPLER RECORD OF FIGURE 4

Times and azimuths are given. The horizontal scales in kilometres give the distance from the radar site at each time. The shower passed directly over the radar site from 1230 to 1255 GMT, and in the pattern for 1254 GMT its trailing edge is not yet clear of the scanning beam of the range–height radar.

in Figure 3 were revealed by gain reduction, and are seen to be close to the leading edge at low levels. They show only slight forward shear. A bright band

was not seen in these patterns, even at reduced gain. At 1254 GMT, when the range of viewing was very short, six fairly uniformly spaced towers could be seen, but comparison with a photograph taken on the same azimuth at 1253 GMT shows that not all were of equal intensity or were at the same stage of development, for some were rising and others were falling back. The spacing of these towers is about 1.5 km, or perhaps 2 km if some allowance is made for them being scattered in azimuth within the beam. Despite its modest size and intensity there was clearly an efficient renewal mechanism in this persistent shower.
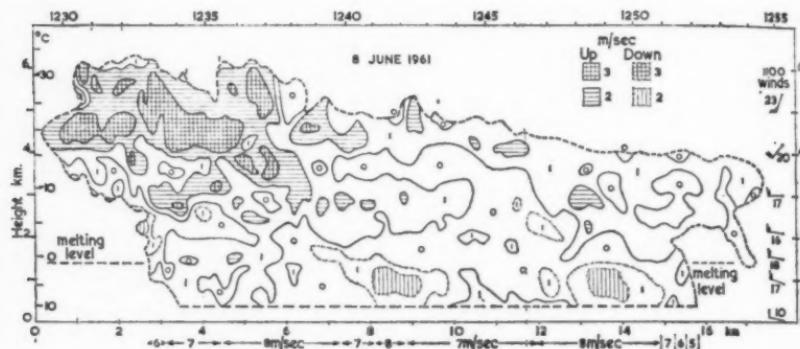

FIGURE 4—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
8 JUNE 1961

The left-hand side is the leading edge of the shower. Wind speeds are given in knots.

The vertical air motion diagram is given at Figure 4. It shows overhang at the leading edge, echo tops reaching 6.1 km in the leading part of the storm, lowering towards the final tail of the shower just above the 3 km level. The strongest upward air motion is found mainly above 4 km, and is almost entirely restricted to the front half of the shower. One can see a suggestion of three towers at a spacing of about 2 km in the pattern of the strongest upward motion, centred at about 1231, 1233 and 1236 GMT, with an echo-free gap about 1 km deep at 1235 GMT. There are further small protrusions at 1239 and 1242 GMT. These features are not dissimilar to those of the echo tops of Figure 3 when the differences of scale are borne in mind.

A surprisingly small amount of downward air motion is found in this analysis compared with the two we have presented earlier, but there is some similarity in the location of the 2 m/sec isopleths, which lie below the melting level and towards the rear of the shower section, with the main cells of downward air motion in Figures 1 and 2.

The two displays of Plate I were taken from this shower. At 1235 GMT (Plate I(a)) there is a fairly broad spread of velocities of 4 to 6 m/sec at most levels, suggesting the presence of liquid water drops or of hydrometeors of similar fallspeed to water drops, but at 3 km it reaches a maximum of 8 m/sec. This could be entirely an effect of drop size, or it could be partly an effect of shear of the vertical air motion within the beam, e.g. if parts of both an up-draught and a downdraught were included within the pulse volume. Plate I(b) taken at 1250 GMT is typical of the pattern towards the rear of the shower,

except during the brief recurrence of irregular motion at 1248 GMT. The spread of 2 m/sec, occasionally 3 m/sec, above the melting level in Plate I(*b*) suggests that snow only is present.

The maximum drop diameter derived from our matching process lies between 2 and 3 mm for most of the shower, tailing off rapidly at the end. But although the Doppler record suggests that rain was reaching the ground from 1234 to 1252 GMT, the rain-gauge recorded a measurable rate only from 1242 to 1247 GMT, with maximum 4 mm/hr. The reason may have been that the southern edge of the shower only skirted the rain-gauge, which is 400 m from the radar site at Pershore, and was slightly south of the cross-section recorded by the radar on this occasion.

Discussion.—A feature of the patterns is their complexity. Perhaps one should not be surprised at this. Attention will be drawn to certain features, however, which may be important, and tentative conclusions drawn from them. (i) In the showers of 8 and 9 April, where there was little variation of wind direction with height, and almost negligible shear of precipitation across the plane of the height–time section, a rough balance between the regions of upward and downward motion is found. On 8 June there was a pronounced unbalance, and it is reasonable to think that this was the result of the substantial wind components across the section at the higher levels on that day (see (v) below).

(ii) The radiosonde ascents show that on all three days shower development was set off by diurnal heating, and that only the rather shallow layer of air heated by the ground would have been convected. The wind patterns given in Figures 1, 2 and 4 suggest that, with a shower movement controlled by the 700 mb wind, there would have been a relative inflow of this surface-heated air into the lower front of the storm. This is without doubt a common feature in such showers.

(iii) In the showers of 8 and 9 April there was little variation of wind direction with height, and therefore negligible shear of precipitation across the plane of the height–time sections. We can for this reason expect to find reasonable continuity in the patterns of vertical air motion between low and high levels.
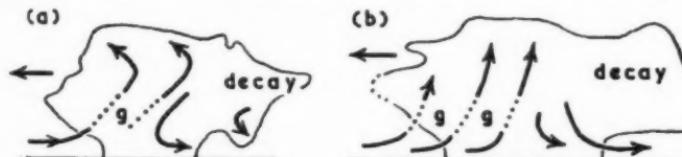
FIGURE 5—SIMPLIFIED PATTERNS OF AIR MOTION SUGGESTED FOR THE SHOWERS OF (*a*) 9 APRIL, AND (*b*) 8 APRIL 1959
The movement of the showers is from right to left.

In Figure 5 we have suggested where these upward and downward motions may be occurring. On 9 April (Figure 5(*a*)) two sloping zones of upward motion are shown (compare Figure 2) in which the vertical component of the air velocity intermittently reaches 2 m/sec. As is implied in the diagram the rearward of the two may be an updraught in which the supply of warm air from low levels has been cut off. The reversal of slope in the stronger up-

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draught above 3 km is consistent with the wind shear present at the time, for the increase of westerly wind above 3 km would have just this effect. The main downward flow has the same slope as the updraughts at medium levels, and lies just behind and beneath the cut-off thermal. It probably leaves the shower either to the sides or to the rear of the section. An almost parallel flow, with its maximum 2 m/sec can perhaps be seen in the tail of the shower, as is suggested by the smaller arrow.

The immediate impression gained from Figure 1 is of updraught from the lower centre to the upper forward region of the shower of 8 April, but this is quite inconsistent with the existing wind shear, and is unlikely to have been the true pattern. We think that the updraught structure must have been more nearly that of Figure 5(b), with inflow into the front of the shower at a low level, and then a more nearly vertical updraught than in Figure 5(a). There should have been no reversal of slope because the wind did not increase above 3 km. Perhaps some slight imagination is needed to see this in Figure 1; a linkage is suggested from the 2 m/sec cell of upward motion at height 2 km, 1328 GMT, to that of 4 m/sec at $3\frac{1}{2}$ km, 1329 GMT, and to 5 m/sec at 4 km, $1329\frac{1}{2}$ GMT; and a second updraught region from the 3 m/sec cell at $2\frac{1}{2}$ km, $1326\frac{1}{2}$ GMT, to the 4 m/sec cell at 4 km, $1327\frac{1}{2}$ GMT, continuing to the echo top at $5\frac{1}{2}$ km, 1328 GMT. These are spaced at about 2 km on the section, which is about the same separation found for the updraughts in Figure 2. This suggests that the small cell of upward motion of 3 m/sec at $2\frac{1}{2}$ km, $1324\frac{1}{2}$ GMT, which is a further 2 km upwind may be a newly developing thermal. The downdraughts are difficult to define in Figure 1 and little reliance should be placed on this section of Figure 5(b).

There is admittedly a lack of continuity in the updraughts through and just above the 0°C level. These portions of the flow lines are dotted in Figure 5 and marked with the letter 'g'. This may well have resulted from the local failure of the assumption that snowflakes or ice crystals are present, for appreciable growth of ice crystals will not occur within the updraught until the temperature has fallen to perhaps −10°C, and it is perhaps unlikely that enough ice crystals or snowflakes will have been caught up in the rising air to be detectable. If in this part of the updraught the slowest-falling particles are small water drops of diameter 0.5 to 1.0 mm with free fallspeeds of 3 to 4 m/sec we shall have underestimated the updraughts here by 2 or 3 m/sec. There is no reason to expect any real uniformity of speed in updraughts. They will usually reach their maxima at upper levels, because of increased buoyancy due to release of latent heat of fusion in regions where supercooled water droplets are freezing, and to the fallout of precipitation. This is probably the reason for the occurrence of the maxima of upward air motion high up, where the air temperatures were −20° to −30°C, in the examples. Lack of uniformity may also arise from the cessation of an updraught or from new development, for updraughts in their early stages, especially at low levels, may not have precipitation in them, and will then not appear at all in the Doppler analysis. Precipitation carried across the beam may also confuse the pattern.

(iv) Another feature in these air motion patterns calling for comment is the almost complete absence of downward air motion at high levels in the active parts of the showers of 8 and 9 April. We can suggest two possible reasons for this. The first is the more obvious one, and stems from the dependence on the

presence of precipitation as an indicator of air movement. It is that compensatory downward air motion is occurring outside the region of precipitation, and so is not revealed by the Doppler analysis. There is no echo-free region within the precipitation boundary of our sections where it could be occurring, and it is perhaps rather unsatisfactory to have to infer that downward air motion at high levels is all occurring elsewhere. This is particularly so since evaporative cooling by falling precipitation, with resulting air density increase, is likely to be a contributory cause of local downdraught, and the probability of occurrence of downward air motion should perhaps be greater where precipitation is present.

The second reason is an instrumental one. In attributing the breadth of spectrum to the range of particle sizes present (p. 274) it is in effect assumed that the radar beam is narrow compared with the regions of updraught and downdraught examined. By deriving a single value of air motion from the right-hand edge of the Doppler pattern we are in fact more nearly recording the strongest upward air velocity (or the weakest downward velocity) contained within the beam at each time. The method gives the correct maximum value for updraught velocity, but overestimates the size of the updraught by an amount equal to the beam width. In Figures 1 and 2 the beam was 210 m wide at height 4 km (the level at which the maximum updraughts are found), but the cells of upward motion are mostly a kilometre or so across, so that the effect is not very important. But further, the method underestimates the size of downdraughts by an amount equal to the beam width, and also underestimates the maxima of downward air velocity. This will also be unimportant in the decaying regions where we find isopleths of downward motion that are measurably broad; but in the active portions of showers, downdraughts that are equal to or less wide than the beam will contribute to the breadth of the Doppler spectrum, but will be entirely lost from the air motion analysis.

(v) This was one reason why the Doppler radar was equipped with a larger aerial in 1960, giving a beam only 1.7° wide (120 m wide at 4 km). We have obtained insufficient shower records with it as yet to decide if a greater proportion of downward air motion is being revealed. The pattern of 8 June (Figure 4) was obtained with this narrow beam, and it seems at first sight that the same difficulty arises. There is a complication however. With the strong cross-wind which was present on this occasion above 3 km continuity of vertical air motion would not be expected between low and high levels in a single section through the shower, and it is likely that the main downward motion was occurring in an adjacent section. The effect of this shear across the beam can be seen in the range–height cross-sections of Figure 3. The stronger cores of echo at 1254 and 1303 GMT do not extend above 4 km, the level at which the cross-wind component has become substantial, undoubtedly because the precipitation is blowing northwards out of the $\frac{1}{2}$ km wide beam. Further, although the cores are at the leading edges of low-level echo, they are clearly not linked with the leading towers at high levels. This suggests that the leading towers, and therefore probably all the towers seen in this section, are being supplied by updraughts which were to the south of the section, and is supported by the fact that the overhang is at 4 km on azimuth 075° but is nearer 3 km on 078°. With these winds the overhang could only have occurred at or above 3 km. The low rainfall at the rain-gauge, which was to the south of the recorded

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section, is also explained by the precipitation being blown northward from the active part of the storm.

Conclusion.—The vertical air motion patterns obtained from Doppler radar records in showers are the first that have been inferred directly. A special feature is that continuous height–time sections are obtained. The patterns in the three showers studied in this paper seem plausible, with two possible exceptions, (i) that updraughts just above the 0°C level may have been underestimated, and (ii) that some of the downward air motion at high levels will not have been detected in the analysis if present in local downdraughts 100 or 200 m in width or if occurring outside the regions of precipitation. We have so far found significant downdraughts only below 700 mb (3 km). The showers we have studied are, however, only modest ones, with rather low rainfall rates, but with improved equipment we hope to examine more active storms.

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551.509.317:551.509.324.2

FORECASTING WET SPELLS AT LONDON

By C. A. S. LOWNDES

Introduction.—For this investigation a wet spell was defined as a period of five days at Kew with (i) at least 15 millimetres of precipitation and no day with less than one millimetre or (ii) at least 20 millimetres with one such day or (iii) at least 25 millimetres with two such days. Lowndes[1] found that in many cases the wet spells were preceded by an outbreak of surface northerlies over the Atlantic and associated trough development in the surface isobars to the west of the British Isles. A study of 500-millibar charts showed that the northerlies were associated with 500-millibar troughs which first appeared over the Atlantic in various longitudes, mainly between 60°W and 20°W. Some were weak over the western Atlantic but intensified during their progression eastward. The average longitude of the trough about 24 hours before the start of a wet spell at London was 30°W in the winter months and 20°W in the summer months. Many of the troughs became slow-moving and some quasi-stationary between 20°W and 0°W. A study was made of 500-millibar contour troughs between 60°W and 0°W over the 10 years 1950 to 1959 and any wet spells which were associated with them were noted. It became clear that the best indicators of wet spells were troughs between 30°W and 20°W and between 20°W and 10°W. No reliable forecasting rules could be based on troughs west of 30°W. A spell indicated by a trough between 10°W and 0°W was nearly always indicated earlier by the same trough between 20°W and 10°W.

Data used.—It was decided to study all 500-millibar contour troughs between 30°W and 20°W and between 20°W and 10°W and to measure their intensity in terms of the 500-millibar height anomaly at 45°N. It became clear, however, that other parameters would be required to distinguish between troughs which were associated with wet spells and those which were not. In a

number of cases, troughs which were not associated with wet spells quickly relaxed on approaching a blocking anticyclone or ridge of high pressure over the British Isles. It was decided therefore to measure the "blocking tendency" in terms of the surface pressure at Valentia or London. This parameter successfully indicated many of the troughs which were not associated with wet spells. However, it was obvious that further parameters were required before a useful forecasting rule could be obtained.

On many occasions, when no wet spell occurred, the spacing to the next upwind trough was short and the trough to the west of the British Isles quickly relaxed or progressed, or was subject to both processes simultaneously. It was therefore decided to measure the spacing between the trough to the west of the British Isles and the next upwind trough and to measure the intensity of the upwind trough in terms of the 500-millibar height anomaly at 45°N.

It was found possible by use of these parameters to obtain rules for the forecasting of wet spells for most months of the year. The data extracted were as follows:

1. (a) The maximum negative 500-millibar height anomaly reached on the trough axis at 45°N between 30°W and 20°W (decametres).
   (b) The surface pressure at Valentia at this time (millibars).
   (c) The spacing to the next upwind trough at this time (degrees of longitude).
   (d) The 500-millibar height anomaly on the upwind trough axis at 45°N (decametres).

2. (a) The maximum negative 500-millibar height anomaly reached on the trough axis at 45°N between 20°W and 10°W (decametres).
   (b) The surface pressure at London at this time (millibars).
   (c) The spacing to the next upwind trough at this time (degrees of longitude).
   (d) The 500-millibar height anomaly on the upwind trough axis at 45°N (decametres).

The data were extracted for the 10 years 1950 to 1959. Mean 500-millibar heights at latitude 45°N for longitudes at 10-degree intervals from 10°W to 120°W are given in Table I; from it the mean 500-millibar height can be obtained for any five-day period. Table I is based on five-year monthly means for the period 1949 to 1953 published by Berlin University.[2]

The critical values of the parameters were found to vary according to the season of the year. The year was therefore divided up into periods during which certain critical values were found to be effective. The periods are as follows:

(a) November to February
(b) March and September
(c) June, July and August.

A successful forecasting rule could not be obtained for April, May and October. In both April and May only four spells occurred during the 10 years. It is possible that a forecasting rule might be obtained for these months from a larger sample of data, when available.

Forecasting wet spells at London in November to February.—For troughs between 30°W and 20°W a diagram was plotted (Figure 1) of the

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TABLE I—500 MB HEIGHT AT 45°N (FIVE-DAY MEANS)

500 *decametres* +

| Period	10°W	20°W	30°W	40°W	50°W	60°W	70°W	80°W	90°W	100°W	110°W	120°W
1–5 Jan.	63	63	62	58	52	47	43	43	42	45	48	50
6–10 Jan.	63	63	62	58	52	47	43	43	42	44	46	49
11–15 Jan.	63	63	62	57	52	47	44	43	42	44	45	47
16–20 Jan.	63	63	61	57	51	47	44	42	42	44	45	47
21–25 Jan.	62	63	60	56	51	46	43	41	42	45	45	47
26–30 Jan.	61	63	60	55	50	44	44	40	42	45	46	48
31 Jan.–4 Feb.	59	62	59	54	49	42	40	39	42	46	49	51
5–9 Feb.	58	62	58	53	48	41	39	38	42	46	50	52
10–14 Feb.	58	61	57	52	46	40	37	37	42	46	50	52
15–19 Feb.	57	59	56	51	44	39	38	38	42	47	51	53
20–24 Feb.	58	58	55	51	42	39	38	38	42	47	51	53
25 Feb.–1 Mar.	58	57	55	50	42	40	39	39	42	47	51	53
2–6 Mar.	59	57	54	50	43	40	39	39	43	47	50	52
7–11 Mar.	59	57	54	51	44	42	41	41	43	47	50	51
12–16 Mar.	59	57	54	51	45	43	41	41	43	47	50	51
17–21 Mar.	59	58	55	52	47	43	42	42	44	48	50	51
22–26 Mar.	59	59	56	53	49	45	43	43	45	50	51	52
27–31 Mar.	60	60	58	55	50	45	44	44	47	52	53	55
1–5 Apr.	60	61	60	57	52	47	45	45	49	53	56	57
6–10 Apr.	60	62	62	59	53	48	45	46	50	55	58	59
11–15 Apr.	60	63	63	61	54	49	47	47	52	57	60	60
16–20 Apr.	60	64	63	61	56	51	48	49	53	58	60	61
21–25 Apr.	60	64	63	61	56	52	50	52	55	59	61	62
26–30 Apr.	61	64	63	61	57	54	52	55	58	61	63	63
1–5 May	61	64	63	61	57	55	55	58	60	62	64	63
6–10 May	61	63	63	61	58	57	57	60	62	64	65	64
11–15 May	61	62	64	62	59	58	59	62	64	66	66	65
16–20 May	62	62	64	62	60	60	61	64	66	67	66	65
21–25 May	63	63	65	62	61	61	63	66	68	68	68	67
26–30 May	64	64	65	62	62	62	65	68	70	70	69	68
31 May–4 June	66	66	66	64	63	63	67	70	71	72	71	69
5–9 June	69	69	68	66	66	65	68	72	73	73	72	70
10–14 June	72	72	70	69	68	67	70	73	75	75	74	72
15–19 June	74	74	73	72	71	69	72	75	76	76	74	73
20–24 June	77	77	75	75	73	72	73	76	77	77	76	74
25–29 June	78	78	77	77	76	75	75	78	78	79	78	76
30 June–4 July	78	79	79	79	77	77	77	79	79	80	80	78
5–9 July	78	79	79	80	78	79	78	79	80	81	82	80
10–14 July	78	79	80	80	79	80	79	80	81	83	84	82
15–19 July	78	79	80	81	79	80	79	80	81	83	84	83
20–24 July	78	79	80	82	80	80	79	80	81	83	84	83
25–29 July	77	79	81	82	80	79	78	79	81	83	84	82
30 July–3 Aug.	77	79	81	82	81	78	78	79	80	82	83	81
4–8 Aug.	76	79	81	82	81	77	77	79	80	82	83	81
9–13 Aug.	76	79	80	82	80	76	76	78	80	82	83	80
14–18 Aug.	76	78	80	81	79	75	75	77	80	82	83	80
19–23 Aug.	76	78	80	81	78	75	74	77	78	81	82	80
24–28 Aug.	75	78	80	80	78	75	74	76	77	80	81	79
29 Aug.–2 Sept.	75	77	80	80	77	75	73	74	75	78	80	79
3–7 Sept.	74	76	79	79	76	75	72	72	74	77	79	78
8–12 Sept.	73	76	78	78	75	74	72	72	72	76	79	78
13–17 Sept.	73	74	76	76	75	74	71	70	71	75	78	78
18–22 Sept.	73	73	74	74	73	73	70	69	70	74	77	77
23–27 Sept.	72	72	72	71	72	71	70	68	69	73	76	75
28 Sept.–2 Oct.	71	70	70	69	71	70	69	68	69	72	74	74
3–7 Oct.	71	68	68	67	68	68	67	67	68	71	73	74
8–12 Oct.	69	67	66	66	66	66	67	67	67	70	72	71
13–17 Oct.	68	66	66	66	65	65	65	66	66	69	71	70
18–22 Oct.	67	65	65	65	65	64	64	65	64	67	70	69
23–27 Oct.	66	65	65	65	65	63	63	63	63	65	68	68
28 Oct.–1 Nov.	65	64	65	66	65	62	61	60	58	63	67	67
2–6 Nov.	64	64	65	65	65	62	59	56	55	61	65	65
7–11 Nov.	62	63	65	67	65	61	56	52	52	58	64	64
12–16 Nov.	62	63	65	67	65	59	53	47	49	56	62	63
17–21 Nov.	60	63	65	67	65	58	49	43	48	55	61	62
22–26 Nov.	60	63	64	66	63	55	46	41	47	53	59	61
27 Nov.–1 Dec.	60	63	64	64	61	52	44	40	46	51	57	59
2–6 Dec.	60	63	64	62	57	49	43	40	44	50	56	58
7–11 Dec.	60	63	64	61	55	47	42	40	43	48	54	56
12–16 Dec.	61	63	63	60	53	46	41	41	42	46	52	55
17–21 Dec.	62	63	63	59	53	46	41	42	42	46	51	54
22–26 Dec.	62	63	63	58	53	46	42	43	42	46	50	53
27–31 Dec.	63	63	62	58	52	46	43	43	42	45	49	51
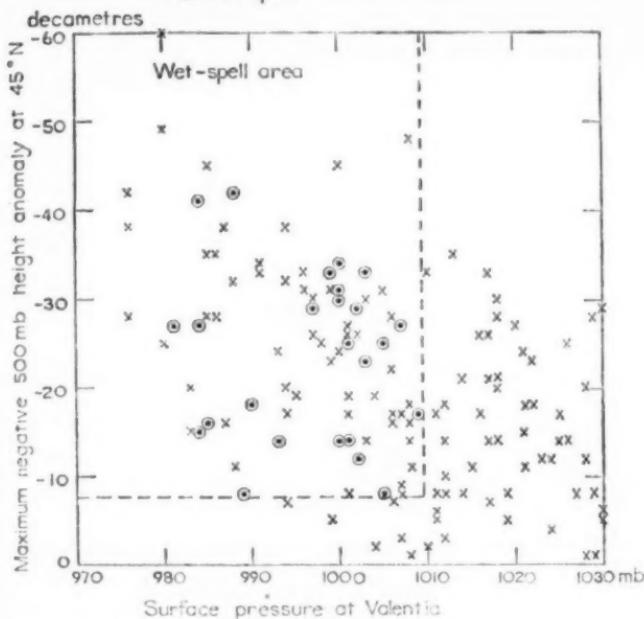
FIGURE I—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS)
FOR TROUGHS BETWEEN 30°W AND 20°W

maximum negative 500-millibar height anomaly at 45°N against the surface
pressure at Valentia at the time of maximum anomaly. If a wet spell began
within two days of the time of maximum anomaly or if a spell had already
begun and continued for a further five days, a circle was plotted. If no wet spell
began within two days, a cross was plotted.

All the wet-spell plots are enclosed within the area indicated. This suggests
that for a trough to be associated with a wet spell, the negative 500-millibar
height anomaly must reach eight decametres and at the same time the pressure
at Valentia must be less than 1010 millibars.

A similar diagram (Figure 2) was plotted for troughs between 20°W and
10°W. In this case, the pressure at London was used instead of the pressure at
Valentia. Most of the wet-spell plots fall within the area indicated. This sug-
gests that for a trough to be associated with a wet spell, the negative 500-
millibar height anomaly must reach 11 decametres and at the same time the
pressure at London must be less than 1008 millibars.

A study of all cases within the "wet-spell areas" showed that if the spacing
between the trough to the west of the British Isles and the next upwind trough
was above a certain critical value, a wet spell usually occurred. However, it
was clear that some upwind troughs in high latitudes and some in low latitudes
could be ignored. Upwind troughs with no troughed contour south of 50°N
and single-contour troughs south of 40°N were not significant. Weak troughs

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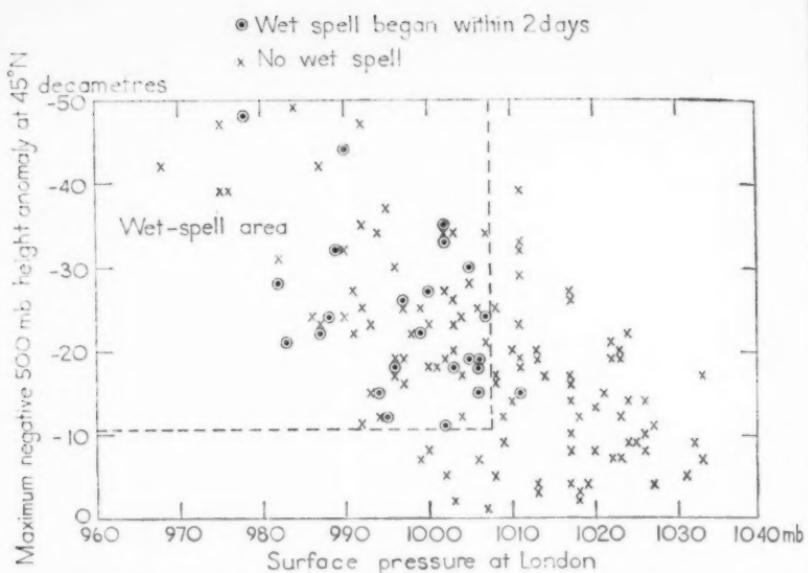
FIGURE 2—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W

with no associated 1000–500-millibar thickness troughs could also be ignored.

For troughs between 30°W and 20°W a diagram was plotted (Figure 3) of the maximum negative 500-millibar height anomaly at 45°N between 30°W and 20°W against the spacing to the next significant upwind trough. The graph can be divided into two areas as indicated. The critical value of the spacing appears to be about 50°. There is some suggestion that for strong troughs it is somewhat higher. Of the 14 cases in the "wet-spell area" 11 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE II—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 30°W AND 20°W

Date	Number of cases
Spell already begun	5
d*	3
$d + \frac{1}{2}$	1
$d + 1$	2

* Spell began within six hours of the time of occurrence of maximum negative anomaly.

Table II shows that the spells had either already begun or that they started within 24 hours of the time of occurrence of the maximum negative anomaly. (The large number of occasions when the spell had already begun is partly due to the use of the maximum negative anomaly as a parameter. On many occasions the troughs intensified during their movement from 30°W to 20°W. The derived forecasting rules define a critical value of the negative anomaly, often less than the maximum value, and therefore in practice an earlier indication of the wet spell will sometimes be obtained. This is borne out by the results of a test of the forecasting rules on the two years 1960 and 1961 given at the end

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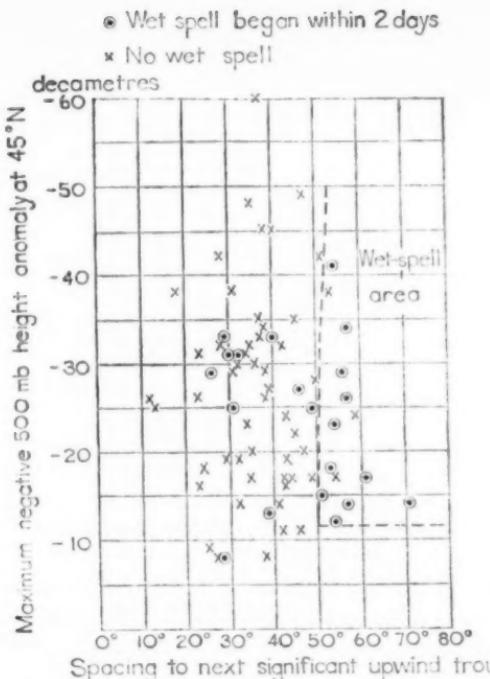
FIGURE 3—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N $\geq$ 8 DECAMETRES AND PRESSURE AT VALENTIA $\leq$ 1009 MILLIBARS

of this paper. The same considerations apply to troughs between 20°W and 10°W.)

For troughs between 20°W and 10°W a diagram was plotted (Figure 4) of the maximum negative 500-millibar height anomaly at 45°N between 20°W and 10°W against the spacing to the next significant upwind trough. The graph can be divided into the two areas as indicated. The critical value of the spacing appears to increase from about 50° for the weaker troughs to over 60° for intense troughs. Of the 15 cases in the "wet-spell area", 13 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE III—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 20°W AND 10°W

Date	Number of cases
Spell already begun	4
d	5
$d + \frac{1}{2}$	3
$d + 1$	1

Table III shows that the spells had either already begun or that they started within 24 hours of the time of occurrence of the maximum negative anomaly. In a number of cases a spell was indicated by a trough between 30°W and 20°W
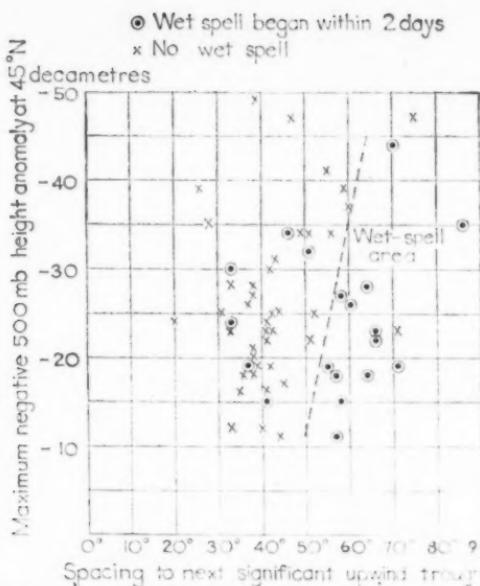
FIGURE 4—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N $\geq$ 11 DECAMETRES AND PRESSURE AT LONDON $\leq$ 1007 MILLIBARS

and again by the same trough between 20°W and 10°W. However, some spells were indicated by troughs between 30°W and 20°W and not by troughs between 20°W and 10°W, and vice versa. Of the 34 wet spells which occurred during the 10 years, 19 were indicated by troughs between 30°W and 10°W.

Rules for forecasting wet spells at London in November to February

Rule based on troughs between 30°W and 20°W

(1) Take note of each chart on which a 500-millibar trough is situated between 30°W and 20°W.

(2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point to the nearest decametre. Calculate the 500-millibar height anomaly.

(3) Note the surface pressure at Valentia to the nearest millibar.

(4) Obtain the longitude of the next significant* upwind 500-millibar trough by estimating the mean longitude of the trough axis to the nearest degree. Calculate the spacing between the two troughs.

(5) If the negative 500-millibar height anomaly between 30°W and 20°W is $\geq$ 12 decametres and the pressure at Valentia is $\leq$ 1009 millibars, plot the

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* A significant upwind trough is defined as having at least one troughed contour south of 50°N and an associated 1000–500-millibar thickness trough. If entirely situated south of 40°N, a single contour trough should be ignored. If the upwind trough is complex and more than one estimate of its longitude can be made, the estimate which is further to the east should be taken.

500-millibar height anomaly between 30°W and 20°W against the spacing to the next upwind trough on the graph (Figure 3). If the plot falls within the "wet-spell area" a wet spell is likely to begin within 24 hours of the time of the trough. Sometimes the wet spell may have begun already and a continuation for a further five days is likely.

Rule based on troughs between 20°W *and* 10°W

(1) Take note of each chart on which a 500-millibar trough is situated between 20°W and 10°W.

(2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.

(3) Note the surface pressure at London to the nearest millibar.

(4) Obtain the longitude of the next significant* upwind 500-millibar trough by estimating the mean longitude of the trough axis to the nearest degree. Calculate the spacing between the two troughs.

(5) If the negative 500-millibar height anomaly between 20°W and 10°W is ≥ 11 decametres and the pressure at London is ≤ 1007 millibars, plot the 500-millibar height anomaly between 20°W and 10°W against the spacing to the next upwind trough on the graph (Figure 4). If the plot falls within the "wet-spell area" a wet spell is likely to begin within 24 hours of the time of the trough. Sometimes the wet spell may have begun already and a continuation for a further five days is likely.

Forecasting wet spells at London in March and September.—For troughs between 30°W and 20°W a diagram was plotted (Figure 5) of the maximum negative 500-millibar height anomaly at 45°N against the surface pressure at Valentia at the time of maximum anomaly. All of the wet-spell plots fall within the area indicated. This suggests that for a trough to be associated with a wet spell the negative 500-millibar height anomaly must reach 11 decametres and at the same time the pressure at Valentia must be less than 1010 millibars.

For such cases, a diagram was plotted of the maximum negative 500-millibar height anomaly at 45°N between 30°W and 20°W against the spacing to the next upwind 500-millibar trough with a negative or zero anomaly at 45°N (Figure 6). The graph can be divided into two areas as indicated. The critical value of the spacing appears to increase from about 50° for the weaker troughs to about 55° for intense troughs. Of the 11 cases in the "wet-spell area" nine were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE IV—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF
MAXIMUM NEGATIVE ANOMALY BETWEEN 30°W AND 20°W

Date	Number of cases
d	2
$d + \frac{1}{2}$	1
$d + 1$	2
$d + 1\frac{1}{2}$	1
$d + 2$	3

Table IV shows that the spells started within two days of the time of occurrence of the maximum negative anomaly. Of the 14 wet spells which occurred

* See footnote on p. 290.
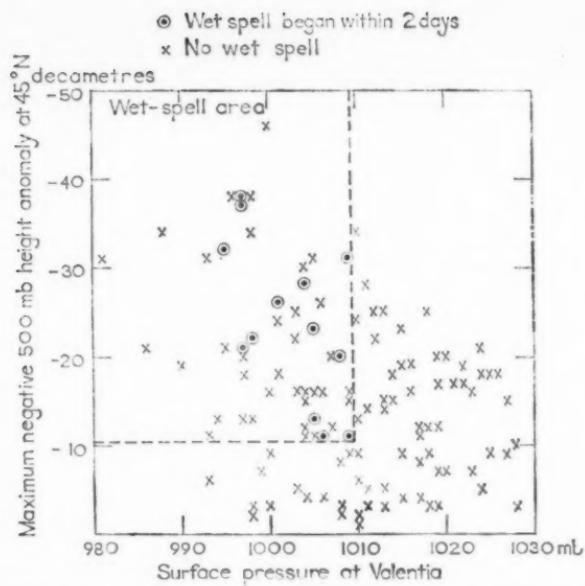
FIGURE 5—WET SPELLS AT LONDON (KEW), MARCH AND SEPTEMBER (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W
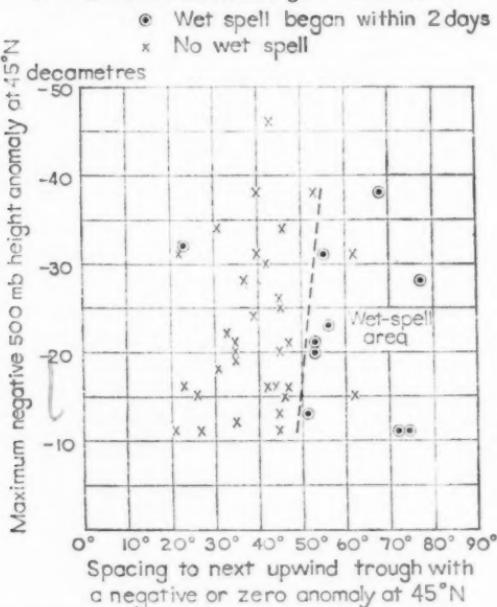

FIGURE 6—WET SPELLS AT LONDON (KEW), MARCH AND SEPTEMBER (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N ≧ 11 DECAMETRES AND PRESSURE AT VALENTIA ≦ 1009 MILLIBARS

over the 10 years, nine were indicated. No useful forecasting rule could be derived from measurements of troughs between 20°W and 10°W.

Rules for forecasting wet spells at London in March and September

(1) Take note of each chart on which a 500-millibar trough is situated between 30°W and 20°W.

(2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.

(3) Note the surface pressure at Valentia to the nearest millibar.

(4) Obtain the longitude of the next upwind 500-millibar trough with a negative or zero anomaly at 45°N using the same procedure as in (2) above. Calculate the spacing between the two troughs.

(5) If the negative 500-millibar height anomaly between 30°W and 20°W is ≧ 11 decametres and the pressure at Valentia is ≦ 1009 millibars, plot the 500-millibar height anomaly between 30°W and 20°W against the spacing to the next upwind trough on the graph (Figure 6). If the plot falls within the "wet-spell area" a wet spell is likely to begin within two days of the time of the trough.

Forecasting wet spells at London in June to August.—For troughs
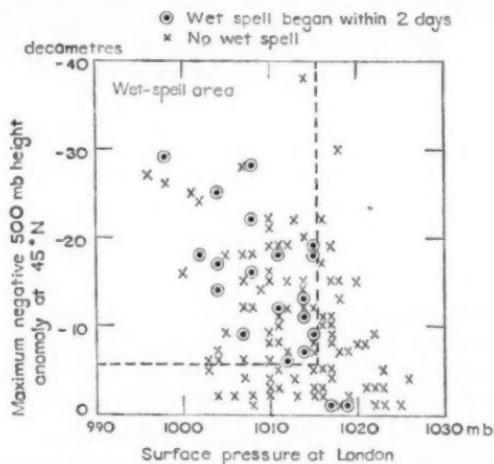
FIGURE 7—WET SPELLS AT LONDON (KEW), JUNE TO AUGUST (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W

between 20°W and 10°W a diagram was plotted (Figure 7) of the maximum negative 500-millibar height anomaly at 45°N against the surface pressure at London at the time of maximum anomaly. Most of the wet-spell plots fall within the area indicated. This suggests that for a trough to be associated with a wet spell, the negative 500-millibar height anomaly must reach six decametres and at the same time the pressure at London must be less than 1016 millibars. Many of the forecast failures indicated by crosses within the "wet-spell area" were found to be associated with situations where the next upwind

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500-millibar trough with a negative anomaly at 45°N was west of 79°W. Excluding these cases, a diagram was plotted of the maximum negative 500-millibar height anomaly at 45°N between 20°W and 10°W against the spacing to the next upwind 500-millibar trough with a negative anomaly at 45°N
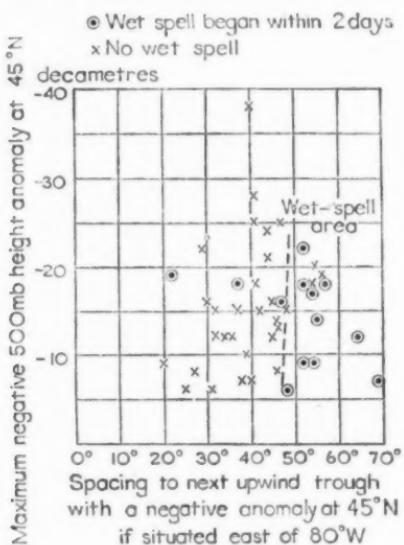

FIGURE 8—WET SPELLS AT LONDON (KEW), JUNE TO AUGUST (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N $\geq$ 6 DECAMETRES AND PRESSURE AT LONDON $\leq$ 1015 MILLIBARS

Excluding cases where the next upwind trough with a negative anomaly at 45°N was west of 79°W

(Figure 8). The graph can be divided into two areas as indicated. The critical value of the spacing appears to be just under 50°. Of the 13 cases in the "wet-spell area" 10 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE V—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 20°W AND 10°W

Date	Number of cases
Spell already begun	1
d	3
$d + \frac{1}{2}$	3
$d + 1$	1
$d + 2$	2

Table V shows that the spells mostly started at varying times within two days of the time of occurrence of the maximum negative anomaly. Of the 25 spells which occurred over the 10 years, 10 were indicated. No useful forecasting rule could be derived from measurements of troughs between 30°W and 20°W.

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Rules for forecasting wet spells at London in June to August

(1) Take note of each chart on which a 500-millibar trough is situated between 20°W and 10°W.

(2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.

(3) Note the surface pressure at London to the nearest millibar.

(4) Obtain the longitude of the next upwind 500-millibar trough with a negative anomaly at 45°N using the same procedure as in (2) above. If the longitude is $\geq$ 80°W a wet spell is unlikely. If $<$ 80°W, calculate the spacing between the two troughs.

(5) If the negative 500-millibar height anomaly between 20°W and 10°W is ≥ 6 decametres and the pressure at London is $\leq$ 1015 millibars, plot the 500-millibar height anomaly between 20°W and 10°W against the spacing to the next upwind trough on the graph (Figure 8). If the plot falls within the "wet-spell area", a wet spell is likely to begin within two days of the time of the trough. Occasionally the spell may have begun already and a continuation for a further five days is likely.

The 500-millibar contour and surface isobaric patterns associated with the forecast wet spells.—In the months November to February, on 13 out of 19 occasions the 500-millibar trough between 30°W and 10°W became slow-moving or quasi-stationary between 20°W and 10°W. On six occasions the trough quickly progressed beyond 0°W and either another trough moved from the west and became slow-moving between 20°W and 10°W or a strong, wide belt of westerlies, in which minor troughs progressed rapidly to the British Isles, formed across the Atlantic. On two occasions the westerlies were centred at 45°N and on one occasion at 53°N.

On surface charts, about half the wet spells were associated with large, slow-moving depressions in the region of the British Isles. The other half were associated with situations in which the main depression was situated south of Greenland, near Iceland or north of the British Isles and secondary lows or waves moved from the south-west or west across the British Isles or along the Channel region. (The six occasions on which the 500-millibar trough between 30°W and 10°W quickly progressed were all associated with the latter situation). About half the situations were blocked, on seven occasions by a high over Russia and on two occasions by a high over Scandinavia.

In March and September, on eight out of nine occasions the 500-millibar trough between 30°W and 20°W became slow-moving or quasi-stationary between 30°W and 0°W. On one occasion the trough quickly progressed beyond 0°W and a new trough developed at 20°W and became quasi-stationary between 20°W and 10°W. On surface charts, the wet spells were associated on six occasions with a situation in which the main depression was situated south of Greenland, south of Iceland or north of the British Isles and secondary depressions or waves moved from the south-west or west across the British Isles or along the Channel region. On the other three occasions, depressions were slow-moving to the south-west or south of the British Isles with blocking highs situated south of Greenland, near Iceland or over Scandinavia.

In the months June to August, on seven out of ten occasions the 500-millibar trough between 20°W and 10°W became slow-moving or quasi-stationary mainly between 10°W and 0°W but on one occasion between 0°E and 10°E. On the remaining three occasions, the trough quickly progressed beyond 0°W and another trough moved from the west and became slow-moving between 20°W and 0°W.

On surface charts, the wet spells were associated on eight occasions with depressions which, in the main, moved very slowly from the south-west across England or the Channel region. Only two of these situations were blocked, one by a high to the north of the British Isles and one by a high over Scandinavia. In both these cases the depression moved along the Channel region. The remaining two spells were associated with a situation in which the main depression was situated north of the British Isles and secondary depressions or waves moved from the south-west or west across the British Isles or the Channel region. There was no blocking on these occasions.

Incidence of thunderstorms.—Lowndes[1] showed that, over the period 1950 to 1959, wet spells (as defined) were often associated with reports of thunderstorms in southern England. He found that during the summer half of the year nearly all the spells were associated with thunderstorms but that during the winter half only about one third to a half were similarly associated.

In the months November to February, 10 of the 19 spells forecast by the rules were associated with thunderstorms in southern England. In March and September, thunderstorms occurred during seven out of nine of the spells and in the months June to August, during nine out of ten of the spells.

Conclusion.—The rules which have been derived for forecasting wet spells at London obtained the following degree of success over the period 1950 to 1959. For the months November to February, 19 of the 34 spells which occurred were forecast and there were four forecast failures. For March and September, nine of the 14 spells which occurred were forecast and there were three failures. For June, July and August, 10 of the 25 spells which occurred were forecast with three failures.

The rules were tested on the two years 1960 and 1961. For the months November to February, six of the 10 spells which occurred over the period were forecast and there was one forecast failure. Four of the six spells were indicated by troughs between 30°W and 20°W and two by troughs between 20°W and 10°W. For March and September, one of the three spells which occurred was forecast with no failure. For June, July and August, four of the six spells which occurred were forecast and there were two failures.

The time lapse between the criteria being satisfied and the beginning of the spell ranged from six to 36 hours for 10 of the 11 successful forecasts. In one case the spell had already begun.

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FORMATION OF WAVES ON WARM FRONTS IN THE VICINITY OF THE BRITISH ISLES

By D. C. E. JONES

Introduction.—A difficult problem which sometimes confronts the forecaster is to decide whether or not a wave will develop on a warm front. Although such a wave may appear as a somewhat insignificant feature of the surface chart, the weather associated with it may be important because of the accompanying rather narrow and fairly fast-moving belt of low cloud and precipitation which often moves into or towards a ridge of high pressure. A wave also tends to retard the movement of the front for a while.

The development of a wave on a warm front and its effect on the weather may be illustrated by events which occurred on 28 February 1961. Late on 27 February and early on the 28th there were indications that a weak ridge would cross the British Isles on the 28th during daylight hours followed sometime later by a warm front. However, with the pressure still rising steadily over the British Isles rain was first reported in north-west Ireland at 0700 GMT. The rain which was associated with a warm-front wave spread rapidly and had reached the south-east of England by the early afternoon. A day which had been expected to be mainly dry over most of England and Wales, under the influence of a weak ridge, turned out with very little warning to be very cloudy with slight or moderate rain in many places.

The formation of warm-front waves in relation to the 1000–500 mb thickness field has been studied by Sawyer[1], who found that the significant criteria for wave development are a slow-moving primary depression and a strong thermal gradient (40–80 knots) of warm-front type ahead of the primary depression and somewhere to the east of it.

Experience has shown, however, that waves are sometimes not accompanied by this 1000–500 mb thickness pattern. It was therefore decided to study the association with features of the pattern at higher levels and this note deals with an investigation of the development of warm-front waves in relation to the flow at levels above 500 mb. Some of the characteristics of the waves during the 12–24 hours following their formation are described.

Selection of the warm-front waves.—In order to obtain a sample of waves the existence of which is known with confidence, it was decided that only waves which formed either over or fairly near to the British Isles would be examined and that selection would be confined to those that produced an appreciable effect on the weather over some part of the country. All the Central Forecasting Office charts for the major synoptic hours for the seven years from 1 January 1955 to 31 December 1961 were examined, and situations which satisfied the following criteria were listed:

(a) a warm-front wave formed within a distance of approximately 400 miles of the British Isles, persisted for at least 12 hours, and crossed over some part of the land areas of the British Isles;

(b) during its passage over the country the wave produced some precipitation along its track.

In connexion with this selection of cases it must be remembered that the sparsity and uneven distribution of ship reports makes the synoptic analysis

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over the Atlantic particularly difficult when dealing with features such as warm-front waves which frequently produce very little distortion of the surface pattern. On this account there is considerable uncertainty regarding the initial position of some of the waves selected for study on the eastern Atlantic.

Characteristics of warm-front waves.—Twenty-eight waves were noted during the seven years concerned—an average of one warm-front wave affecting the British Isles in three months. The positions at which they first appeared
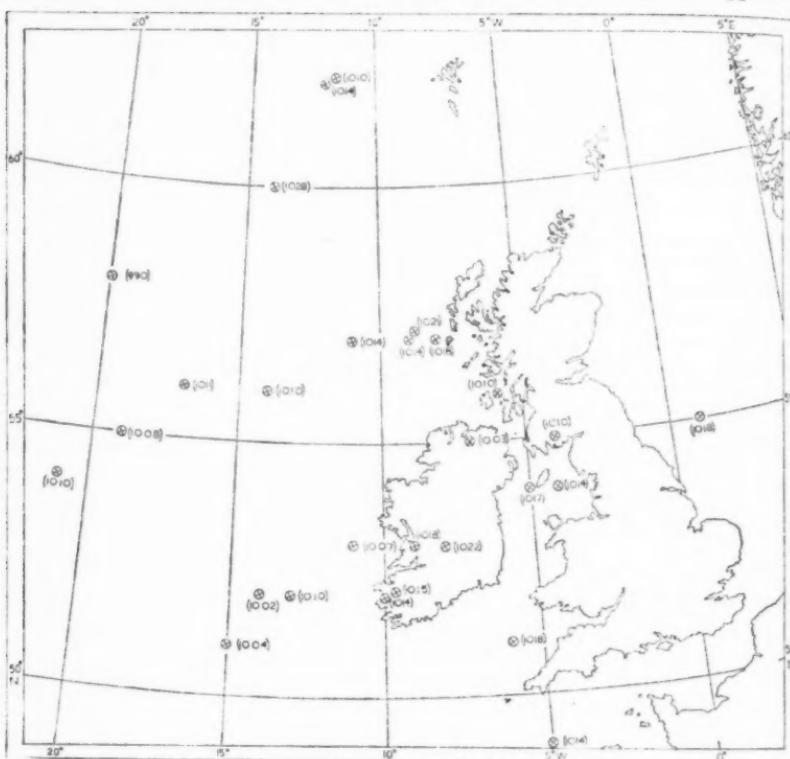
FIGURE I—POSITIONS OF FORMATION OF WAVES STUDIED
Figures in brackets are surface pressures at the time of formation.

are shown on a map in Figure 1. In the 12 to 18 hours after formation, their direction of motion varied between 060 and 170 degrees, the average being about 110 degrees.

Figure 2 presents the frequency of various speeds in the form of a histogram. A fairly wide range of speeds was observed, 50 knots being the highest in the sample studied and 33 knots the average.

The frequency of various central pressures at the time of formation is shown in Figure 3. A range varying from 990 to 1028 mb was found but 19 of the 28 waves formed at a point where the pressure was between 1010 and 1020 mb. In most cases the wave was translated along the warm front without deepening
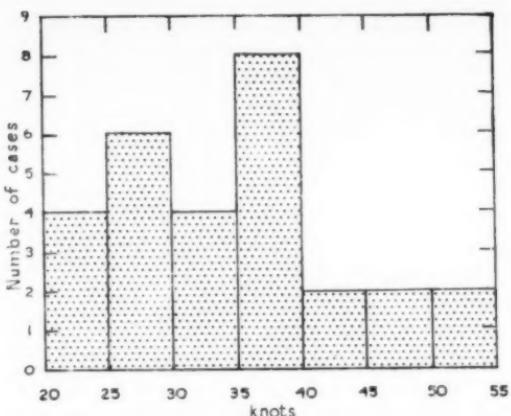
FIGURE 2—FREQUENCY OF SPEEDS OF WARM-FRONT WAVES
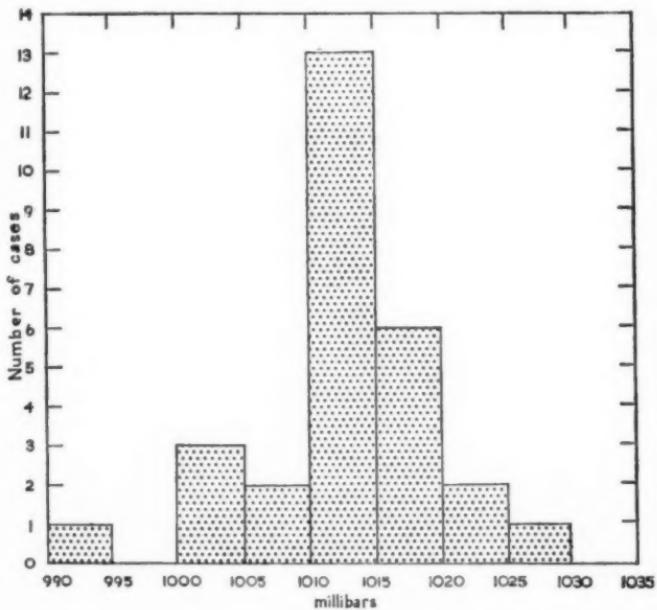
FIGURE 3—FREQUENCY DISTRIBUTION OF CENTRAL PRESSURE OF THE WAVES
AT THE TIME OF FORMATION

and in a substantial number of occurrences the central pressure was rising as
the wave moved into or towards a region where the pressure was already high.
There were no closed isobars (drawn at 2 mb intervals) associated with 22 of
the waves and only one had more than two closed isobars.

The above characteristics are in reasonable agreement with previous findings[1]
but it must be remembered that the previous investigation was concerned with
a sample taken from a wide area extending from the Rockies to the Urals
whereas the present sample was drawn from a much smaller area near the
British Isles.

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Examination of waves in relation to high-level charts.—The suggestion has been made in two recent papers[2, 3] that stratospheric thickness charts (200–100 or 300–100 mb) might prove valuable in forecasting warm-front waves. In an attempt to investigate the value of this suggestion, the waves were examined in relation to the 300–100 mb charts but the result was inconclusive, probably because of the uncertainty in the construction of the 300–100 mb thickness field from the 300 and 100 mb charts.

The waves were next examined in conjunction with the broad features of the 300 mb contour charts and it was found that 22 had formed near the right entrance to a jet stream in which the maximum speed of the jet exceeded 60 knots. These 22 cases were further examined as follows.

The direction of motion of the waves in relation to the general direction of
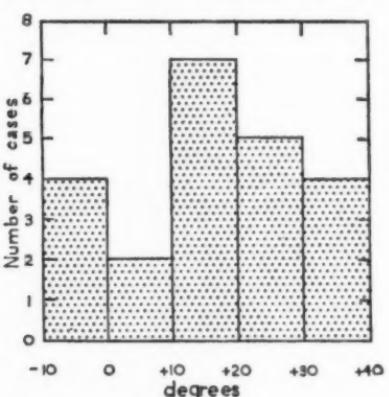
FIGURE 4—DIRECTION OF MOTION OF WAVE IN RELATION TO THE 300 MB JET
Positive values indicate deviation to the left, that is towards the cold air.

the contours of the jet on the 300 mb chart was noted and Figure 4 gives this information in the form of a histogram. The direction of movement of the waves is very close to the direction of the 300 mb contours, being on average inclined at an angle of about 15 degrees towards the cold air.

An attempt was made to correlate the wave speeds with the 300 mb wind speed as measured from the contour charts by taking the average speed over a distance of about 200 miles across the flow in the region of the jet stream and along the path of the wave (Figure 5). The wave speed was found to be approximately one-third of the jet stream speed at 300 mb and about half of the 300 mb wind speed along the path of the wave. These rules gave slightly smaller mean errors than the rule suggested by Hoyle[4] for the speed of warm-sector waves in straight 1000–500 mb thickness patterns. Also, from a practical point of view, it was found generally easier to obtain representative wind measurements from the 300 mb charts than from the thickness charts because on many occasions the wave travelled along a path where the thermal wind was changing rapidly at right angles to the path thus making it difficult to obtain a representative mean thermal wind.

The waves travelled on the warm side of the jet stream at a distance mainly between 100 and 250 miles from the axis of the jet stream which was itself moving slowly east or north-east, with a speed rarely exceeding 20 knots.

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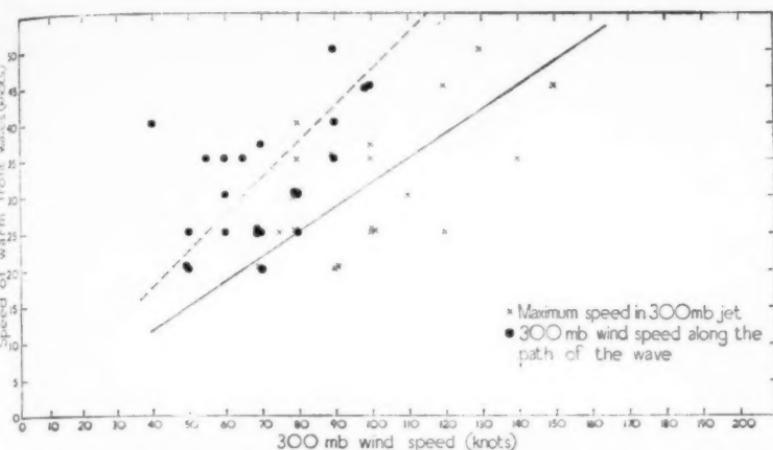
FIGURE 5—SPEED OF MOVEMENT OF WARM-FRONT WAVES PLOTTED AGAINST 300 MB WIND SPEEDS

Speeds were measured over 200 miles taken across the flow in both cases.

In 20 out of the 22 cases the warm front was to the east of the 300 mb ridge and remained in this position for a considerable time before the wave formed. It is difficult to fix a time when the situation first becomes favourable for a wave to form. The process is probably gradual but a time lag of the order of 12 to 24 hours seems usual from the time that the warm front gets to the east of the ridge and into a position somewhere near the right entrance to the jet. During this period of 12 to 24 hours before the formation of the wave, on nearly all occasions the 300 mb pattern remained substantially unchanged over the British Isles and the eastern Atlantic. A depression somewhere near or over Scandinavia (but sometimes between Iceland and Scandinavia) with an anticyclone to the south or south-west of the British Isles, is a typical surface situation in which the waves formed.

Regarding the remaining six waves which did not form near the right entrance to a jet stream, four of them were associated with jet streams (one not far from a jet exit). The fifth was to the east of a ridge and might possibly be classed as being near the entrance to a narrow jet but this was rather doubtful. The sixth was near a confluence in which the wind maximum was too low to be classed as a jet stream.

It was concluded that a rule which might be of some use in predicting wave formation is that, the warm front must become slow-moving near the right entrance to the 300 mb jet and on the east side of a 300 mb ridge.

An example of a wave which formed off north-west Ireland and moved across the north of England at a speed of about 20 knots is shown in Figures 6(a)-(c).

Forecasting test.—In order to assess the practical value of this suggested rule using the 300 mb chart, a forecasting test was made on all the warm fronts that crossed the British Isles, without producing waves, during the two years 1958 and 1959. There were 85 fronts, nine of which were not associated with a 300 mb ridge because the fronts were rather weak and superficial. Of the

301
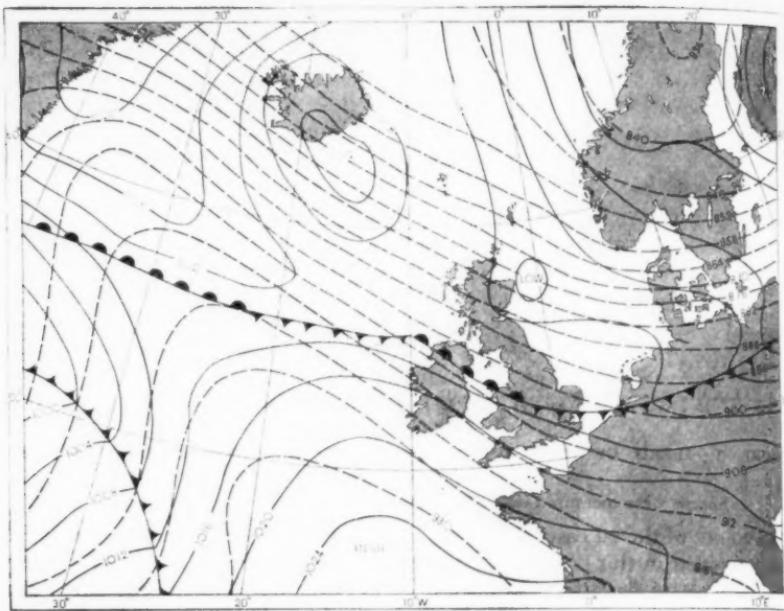
FIGURE 6(a)—SURFACE AND 300 MB CHART FOR 0001 GMT, 31 MARCH 1961
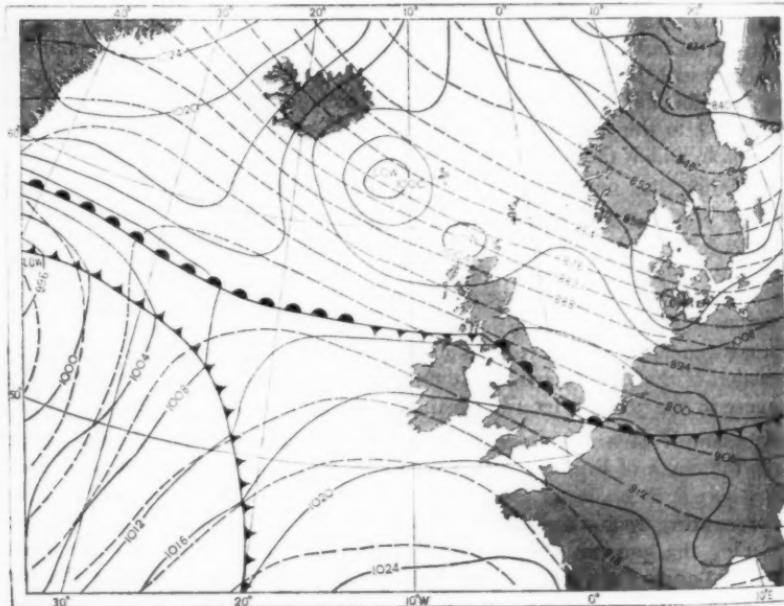

FIGURE 6(b)—SURFACE AND 300 MB CHART FOR 1200 GMT, 31 MARCH 1961

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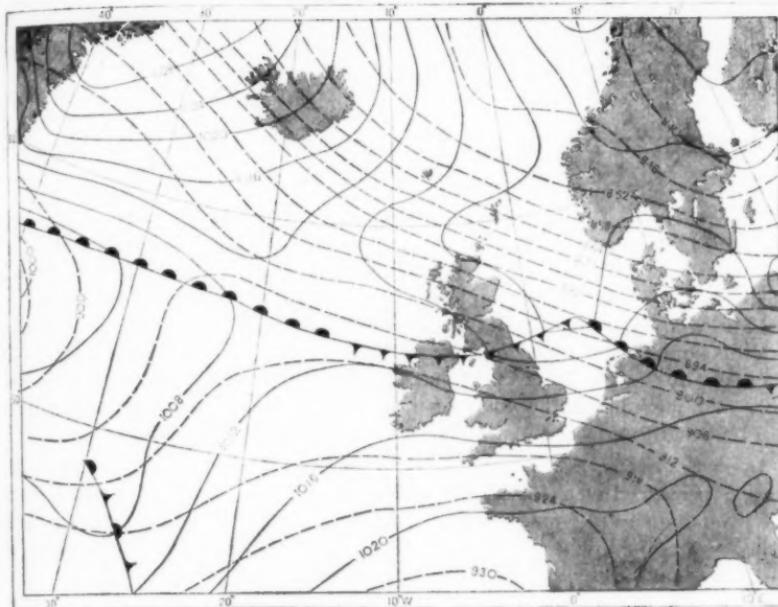
FIGURE 6(c)—SURFACE AND 300 MB CHART FOR 0001 GMT, 1 APRIL 1961

remaining 76, it was judged that nine satisfied the double requirement of being in the vicinity of a jet entrance and to the east of the 300 mb ridge. Thus by taking into account the 11 waves which occurred in the two years, the result of the test for the two years is that of the 96 warm fronts, which either crossed or reached the vicinity of the British Isles, 17 of them would be expected to wave but only eight actually did so. Three waves would have formed without being forecast.

Conclusion.—Some of the characteristics of warm-front waves which formed in the vicinity of the British Isles during the last seven years were examined. A notable feature is that their frequency is small, being on average only about four a year. Their speed varied from 20 to 50 knots and their direction of motion varied between 060 and 170 degrees.

The possible use of charts above 500 mb for predicting their occurrence was investigated. It was found that an empirical rule which requires the warm front to be in a position near the right entrance to a jet stream on the 300 mb chart, and also to the east of the 300 mb ridge, was reasonably successful in view of the small number of occasions on which waves develop. This method showed about the same degree of accuracy as Sawyer's method[1] using the 1000–500 mb thickness pattern. It has the advantage that it is based essentially on a wind field at one level, and direct observations are therefore available to the forecaster every six hours.

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551.515.8:551.589.5
# UNEXPECTED DELAYS IN CLEARANCES BEHIND COLD FRONTS
By R. M. MORRIS

At the passage of an anafront precipitation is fairly heavy and steady rain continues for some time behind the front while clearance of cloud is slow. At the passage of a katafront amounts of precipitation are slight or nil and cloud clears rapidly and often completely. The characteristics of the two types of cold front are well known and recognition of the type on a particular occasion usually enables the times of clearance to be forecast with fair accuracy. It occasionally happens, however, that an unexpected delay occurs in the clearance of low cloud, and sometimes in the clearance of rain, and a forecaster can be caught unawares.

In 1959 forecasters at meteorological offices where such unexpected delays were experienced were invited to list future occasions in order that a study of the problem could be made. Between October 1959 and June 1961, 45 cases of delays were noted. The length of the delays ranged from two or three hours up to fifteen hours. Fifteen occasions were reported from Kinloss, ten from Manchester, and between five and ten from Ballykelly, Nutts Corner, Chivenor and St. Mawgan; three occasions were reported from Gaydon, one from each of Prestwick and Ternhill, and no occasions from Aldergrove, Valley, Manby, Stradishall and Bovingdon. Considering that about 100 cold fronts would have crossed the British Isles in the period of observation, it is seen that at any one place a delay in clearance is not very frequent. The phenomenon seems to predominate in Northern Ireland, the western coast of England, and additionally the Moray Firth.

Mostly the delays were local, occurring at one meteorological office only, but on nine dates a delay was experienced at two offices and on three of these at three offices. On six of the nine dates the delay was in the clearance of rain and not in the lifting of low cloud.

It soon became clear that two separate problems were involved; a delay in clearance of rain was not necessarily accompanied by a delayed clearance of cloud at low levels, low enough, that is, to impede aircraft operations, and a delay in clearance of low cloud was not always associated with a delayed clearance of rain. In the case of rain the problem appears to be on a broad, synoptic scale affecting a few places, whereas in the case of low cloud it is on a local, meso-scale, often affecting one place only.

Delay in cessation of rain.—On 24 of the occasions the frontal surface lay near radiosonde stations and the upper air data were used to construct time cross-sections. Two cases were complex involving a new frontal system with precipitation spreading ahead. In the remaining 22 cases the behaviour of the thermal trough in the 1000–500 mb thickness field was examined for meridional extension or relaxation. The results of the examination are given in Table I. Although the sample is a small one, it suggests that delays in clearance of rain are associated with relaxing, rather than with extending, troughs.
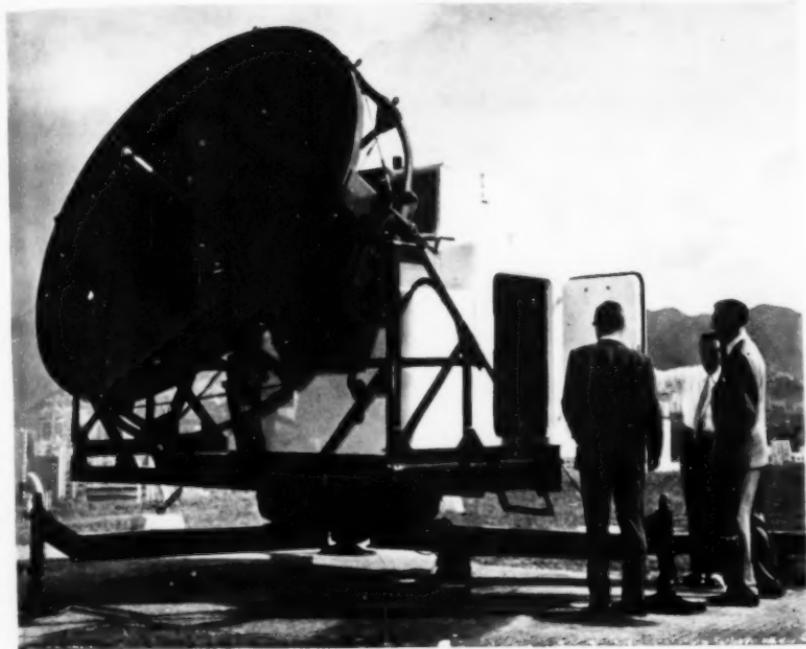
Hong Kong Government Information Services — Crown Copyright.

PLATE IV—HONG KONG ROYAL OBSERVATORY'S RADIOSONDE STATION AT KING'S PARK

His Excellency the Governor of Hong Kong, Sir Robert Black, is shown about to enter the operator's cabin of the wind-finding radar on 18 July 1962.


By courtesy of B.E.A.

PLATE V—CAPTAIN R. FOWLER OF B.O.A.C. (LEFT) AND CAPTAIN D. MASON, A.F.C. OF B.E.A. (RIGHT) WITH DR. A. C. BEST, C.B.E., D.SC.
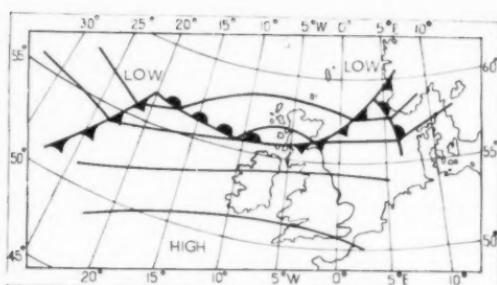
Type I—Cold front returning as warm front
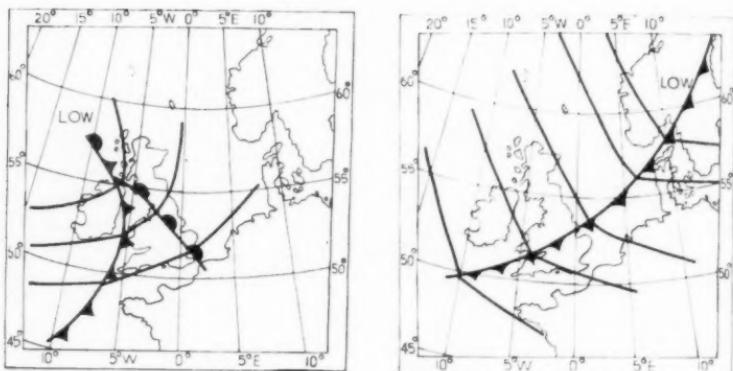
Left. Type II(*a*)—Cyclonically dominated; main centre west of British Isles
Right. Type II(*b*)—Cyclonically dominated; centre and front moving with little retardation
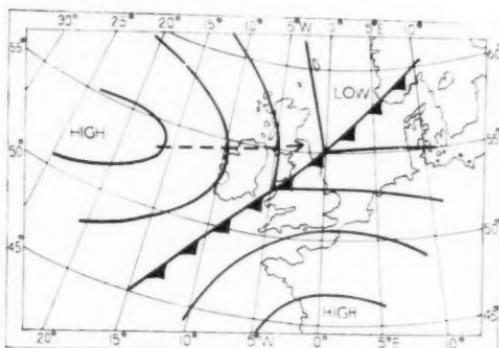
Type III—Anticyclonic curvature

FIGURE I—CLASSIFICATION OF RELAXING TROUGHS

Accordingly, 91 examples of relaxing troughs were studied to see whether the associated surface patterns could be classified and, if so, whether one class could be associated with area of delay in the cessation of rain. It was found possible to classify almost all the relaxing troughs into three types, as follows:

Type I—Cold front returning as a warm front. This is a mobile type with a non-developing ridge behind the cold front and little change in wind direction across the front.

Type II—Cyclonically dominated. The isobars behind the cold front are cyclonically curved or straight. The main centre may (*a*) linger west of the British Isles or (*b*) move into Scandinavia with the cold front progressing well into the Continent with little retardation.

Type III—Anticyclonic curvature. The isobars ahead of the cold front are curved anticyclonically and a new cell of high pressure is developing in the cold air. With marked anticyclonic curvature, *there is a considerable change in wind direction across the front.*

These types are illustrated in Figure 1. Type I comprised about one third of the cases and rain behind the cold front was insignificant or nil. Type II comprised about half the cases and again the rain behind the cold front was mostly insignificant, although there was sometimes substantial rainfall ahead of it. Type III was rare, comprising about one sixth of the cases, and it was in this category that delays in the cessation of rainfall were found to occur.

In Type III, when the wind shear is well marked, minor ripples move along the front and despite the overall rise of pressure, a large area of medium cloud and rain appears to spread back over the cold air and move only very slowly. Good examples occurred on 10 May 1958, on 29 January and 31 May 1959, and on 12-13 January 1961.

TABLE I—RELATION BETWEEN THE THERMAL TROUGH AND THE DELAY IN THE CLEARANCE OF RAIN

Precipitation in rear	Relaxing troughs	Unchanging troughs	Extending troughs	Total
		number of occasions		
None	5	2	2	9
Short period	1	5	0	6
Long period	5	2	0	7
Total	11	9	2	22

Re-examination of the 22 cold fronts, on which Table I is based, showed that those with significant rainfall in the cold air which could not be ascribed to waves on the cold front were all associated with the growth of an upwind upper ridge and some intensification of surface pressure in the cold air, a characteristic of Type III. The relative infrequency of Type III is consistent with the rarity of unexpected delays in the cessation of rain.

Delay in clearance of low cloud.—As has been stated above, delay in clearance of low cloud varies from place to place and does not appear to be a broad feature of a certain type of front, although fronts with minor waves may effectively contribute. Local topography is evidently an important factor and, as delays are rarely experienced inland, proximity to the sea seems to be important also. Rain falling through cold air could cause a delay in the clearance of low cloud but on the whole a delay in clearance of rain and low cloud simultaneously is rare.

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Examination of the distribution of winds, temperature and humidity aloft indicated a retardation in the surface layers and often at higher levels also, relative to the layer between about 900 and 800 mb. The "nose" thus formed at about 850 mb appears to descend later to the ground, trapping a pocket of warmer air. The retardation of the surface layers relative to those at about 900 mb is common at cold fronts and it does not appear that this effect alone can distinguish those with delayed cloud clearance from those without.

The following parameters are among those which it is thought may be related to an unexpected persistence of low cloud behind a cold front:

(a) Wind speed and direction in the cold air.
(b) Adjacent sea temperature.
(c) Fall of wet-bulb potential temperature across the front.
(d) Difference between the sea temperature and the wet-bulb potential temperature in the cold air.
(e) Stability in the lower layers on either side of the front.
(f) Rain falling through the cold air.

The rarity of the phenomenon hampers the accumulation of sufficient data for a statistical study. A minor study of the parameters listed above in 24 cold fronts indicated that the relative importance of parameters varies from place to place. At Prestwick, for example, the difference between the sea temperature and the wet-bulb potential temperature in the cold air yields a fair correlation with persistence of low cloud, whereas at Manchester there is no such correlation; at Manchester there appears to be some correlation with rain delays whereas there is no correlation of this sort at Aldergrove or Kinloss. The highest correlation found was with wind direction in the cold air at Kinloss; it was approximately 0.70.

It is believed that no single forecasting rule will apply at every place and that, probably on account of the importance of local topographic effects, progress in formulating rules will depend upon a study of local parameters whenever the phenomenon occurs.

REFERENCE

1. SANSOM, H. W.; A study of cold fronts over the British Isles. *Quart. J.R. met. Soc., London*, **77**, 1951, p. 96.

NOTES AND NEWS

Meteorological Office awards to captains and navigators of civil aircraft

The valuable assistance given by British airline pilots in supplying the Meteorological Office with weather reports made in flight was recognized in a ceremony held at the headquarters of the Guild of Air Pilots and Air Navigators on 12 July 1962.

The Master of the Guild, Captain J. T. Percy, opened the ceremony and introduced Dr. A. C. Best, Director of Services of the Meteorological Office. Dr. Best spoke of the importance of aeronautical meteorology. This was particularly emphasized by the fact that the term "non-aviation inquiries" was frequently used to include together all questions which were not related to flying.

Dr. Best then presented handsome briefcases to Captain Derek Mason, A.F.C., a senior B.E.A. pilot, and to Captain Raymond Fowler, master of

Boeing 707 flights with B.O.A.C. The awards were made for "long and meritorious service in the provision of weather reports".

In replying the pilots said that they hoped the assistance they were able to give in making the observations would help to repay some of the invaluable service continuously provided to pilots and aircrew by the Meteorological Office.

Books are being sent to the following captains and navigators for their weather reports:

Captain B. E. P. Bone, B.O.A.C.
Captain E. Caesar-Gordon, B.E.A.
Captain W. N. C. Griffiths, B.O.A.C.
Captain A. C. Hellary, B.U.A.
Captain A. R. Martin, B.E.A.
Captain N. A. Mervyn-Smith, B.O.A.C.
Captain M. H. Reveller, B.O.A.C.

Captain G. Thomas, B.U.A.
Captain B. J. Thwaites, B.E.A.
Captain F. A. Tricklebank, B.E.A.
Navigator T. N. Bailey, B.O.A.C.
Navigator J. F. H. Clarke, B.O.A.C.
Navigator R. E. Holloway, B.O.A.C.
Navigator J. W. Morgan, B.O.A.C.

Navigator T. K. Prince, B.O.A.C.

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 15—*The errors of the Meteorological Office radiosonde, Mark 2B*, by D. N. Harrison, O.B.E., D.Phil.

The author presents the results of a long series of experiments designed to test the accuracy of the instruments which are used to obtain daily observations of temperature and humidity at high levels in the atmosphere. The possible origin of instrumental errors of various types and their effect in synoptic meteorology are briefly discussed, and references are given to other work in the same field.

PUBLICATION RECEIVED

Steam fog in Greek seas, by B. D. Kyriazopoulos and G. C. Livadas. $9\frac{5}{8}$ in. x $6\frac{3}{4}$ in., pp. 88, *illus.*, Meteorological Institute of the University of Thessaloniki, 1961.

METEOROLOGICAL OFFICE NEWS

Sports activities.—The second Annual Sports Meeting organized by the Bracknell Social and Sports Club was held on the evening of 28 June, in fine weather, at the Palmer Park Running Track, Reading.

The various events, open to all members of the Staff of the Meteorological Office, were well supported. A strong contingent from London Airport all acquitted themselves well, and there were also competitors from Abingdon, Bomber Command, High Wycombe, Larkhill, Manchester, Porton and Uxbridge.

There was one new record established namely, 220 yards men, by Mr. J. Miller, M.O.2, in a time of 24.1 seconds. M.O.2 and M.O.9 shared the cup awarded annually to the Branch gaining the most points at the Sports.

Among the many spectators were Sir Graham Sutton, C.B.E., F.R.S. (Director-General) and Lady Sutton and Dr. A. C. Best, C.B.E. (Director of Services) and Mrs. Best. The presentation of prizes was made, at the conclusion of a very successful evening, by Dr. R. C. Sutcliffe, C.B., F.R.S. (Director of Research) and Mrs. Sutcliffe.

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